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EFFECT OF ROTATIONAL SPEED ON MICROSTRUCTURE AND MICROHARDNESS OF BORON CARBIDE REINFORCED AA2014-T6 NANO SURFACE COMPOSITES

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ABSTRACT

Aluminum and its alloys are the most important engineering materials due to their good ductility, resistance to corrosion, high strength and low density. AA2014-T6 finds applications in aerospace and defense industries and is used in heavy-duty forgings, extrusions for aircraft fittings, wheels, etc.., The objective of this present work is to investigate the influence of tool geometry (tapered cylindrical pin profile), tool rotational speed and volume % of reinforcement of nano B_4C powder on mechanical properties of friction stir processed AA 2014/T6 aluminum alloy 6mm, thickness plates. Boron carbide is an extremely hard boron, carbon ceramic and covalent material and finds its applications in tank armor, bulletproof vests, engine sabotage powders, etc. In this investigation an attempt is being made to understand the effect of tool rotational speed at 2 volume percentage (Vol. % 2) of reinforcements (nano B_4C) using tapered pin profile with concave shoulder radius of R2.5 on microstructure and microhardness of surface-based AA 2014-T6/B_4C nanocomposites via friction stir processing (FSP). The microstructure is examined by using an optical microscope. The observed microhardness values are to be correlated with their microstructure.

KEYWORDS: Friction Stir Processing, Reinforcements, Microstructure & Micro Hardness

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Original Article

INTRODUCTION

Tailored properties [1] are obtained by reinforcing hard ceramic particles into a matrix, usually an alloy. Such types of engineered components are Metal Matrix Composites (MMC's) possessing improved mechanical properties that are intermediate between the matrix alloy and the ceramic reinforcements such as high specific strength, damping capacity, specific modulus and good wear resistance compared to unreinforced alloys. The aluminum matrix can be strengthened by reinforcing it with hard ceramic particles like SiC, Al_2O_3 & B_4C etc. as there is a huge demand in such composites due to low density, high strength to weight ratio and improved resistance to fatigue and wear [2]. Such characteristics make them promising materials for aerospace and automobile industries [3]. It is found that homogenous dispersion or decrease in the size of ceramic particulates and/or matrix grains from micrometer to nanometer level [4] -[6] is beneficial to enhance the mechanical properties of Aluminum Matrix Composites (AMC's) [7]. Several methods are used to fabricate particulate reinforced composites such as powder metallurgy route, stir casting, friction stir processing, etc, but much attention has been paid to friction stir processing (FSP) as a solid-state, emerging efficient processing technique to fabricate surface composites. FSP is developed from Friction Stir Welding (FSW) as a surface modification technique to improve surface properties [8] of the base material

by adding reinforcements. FSP is a plastic deformation technique and uses a non-consumable tool similar to the FSW tool with shoulder and pin. The rotational tool with pin and shoulder is plunged into the surface and moved over the desired surface. Due to the rubbing action between tool shoulder and base metal surface frictional heat is developed, and plastic deformation takes place with stirring action of the rotational tool. In the stir zone, the material suffers microstructure modification [9]. Aluminum alloys have wide structural applications in aerospace, transportation, and military due to its low density, high strength to weight ratio and resistance to corrosion. But its poor wear resistance makes it limited for several applications [10]. To overcome these B_4C reinforcements are to be added to the base material and processed using FSP. H. G. Rana et al. Investigated the effect of B_4C reinforcements (12-15μm) in the fabrication of Al7075/B_4C surface composite by novel Friction Stir Processing. A heat treated WC-CO (12%) tool with taper cylindrical pin profile is used for stirring process. The process parameters varied were tool rotational speed and transverse speed. It is found that Avg. the hardness of the processed sample has been increased by 1.3-1.6 times of the base metal (75-80Hv) at lower transverse speed. It is also found that the wear resistance is observed to be highest at a lower transverse speed which is attributed to the higher amount of distribution of B_4C particles and grain strengthening mechanism [11]. The fine distribution of additive particles without agglomeration will result in good mechanical properties [12]. The porosity and interfacial reaction between matrix and reinforcement are avoided as the processing is done below the melting point temperature of the base plate via FSP. In the present work, an attempt is being made to fabricate AA2014-T6/B_4C nano surface composite using FSP and study the effect of tool rotational speed at 2 Vol % of reinforcements (Vol % 2), weld speed of 20mm/min on the microstructure and mechanical properties of the same.

MATERIALS AND METHOD

Base metal or AA2014-T6 i.e., substrate with chemical composition (% of weight) consists of 3.9-5% copper, 0.5-0.9% silicon, 0.4-1.2% manganese, 0.2-0.8% magnesium, 0.25% zinc, 0.5% iron, 0.15% titanium, 0.1% Cr and the remaining is aluminum. The friction stir processing was carried out on an indigenously built FSW machine. The process parameter varied is tool rotational speed at 2 volume percentage of reinforcements (Vol. % 2) keeping welding speed, tool, tilt angle, axial force constant. A tapered pin profile with concave shoulder radius of R2.5mm is taken for processing. Commercially available Aluminum alloy AA2014-T6 plates of 200 mm in length, 120 mm in width and 6 mm in thickness were used in the fabrication of nano surface composites by using nano B4C reinforcements of average particle size (APS<40 nm) and the purity>99%. Boron carbide (B4C) has excellent chemical and thermal stability, high hardness and low density and is used for manufacturing of armor tank, neutron shielding material, etc To reinforce nano B4C particulates into the base metal, a groove with 5.7-mm depth and 0.5mm width (Vol % 2) are machined on the base metal as shown in Figure 1. The desired amount of nano B4C powders is filled in the groove before FSP was carried out. Initially, a tool with the only shoulder is used for packing the powder in the holes at some particular tool rotational speed and weld speed so as to not to allow the powder to fly off. Later the selected tool with desired process parameters is used to fabricate the nano surface composites. Improved surface properties with the detainment of bulk properties are necessary for a component for an enhanced increase in hardness and wear characteristics. The direction of processing is normal to the rolling direction. The single pass technique procedure is used to fabricate the nano surface composites. A non consumable tool made of H13 tool steel is used to fabricate the composite. The tool is heat treated to enhance its hardness and improve its wear resistance property. A tapered tool with a diameter of shoulder 24 mm, pin diameter of 8/6mm and pin length 5.6mm (depends on the plate thickness) with concave shoulder radius of R2.5 mm is used. The fabricated tool without and with heat treatment are shown in Figure 2. The mechanical properties of the base metal are shown in Table 1.

Experiments were conducted to fabricate the composites at varying rotational speeds, i.e., 1300, 1350,1400,1500,1600 and 1800 revolutions per minute and at a constant feed rate of 20mm/min, the tilt angle of 1^0, the tool vertical force of 5KN. The surface morphology of the processed regions at different rotational speeds is shown in Figure 3 (a-f). It was found that the tracks of the rotational tool have a specific pattern in the form of onion rings as can be seen in Figure 3. (a-f).

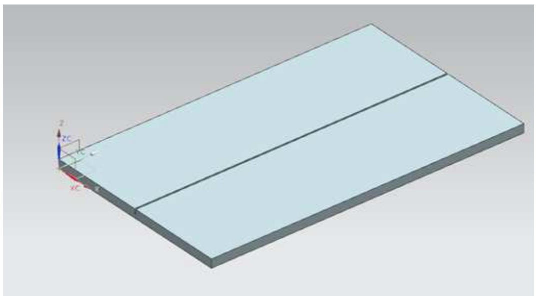

Figure1: Schematic Diagram of Groove of Width 0.5mm Machined on the Base Plate

Figure 2: Tapered Tool Before and After Heat Treatment

Table 1: Mechanical Properties of the Base Meta006C

Base Metal	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation %	Micro Hardness (HV)
AA2014-T6	414	483	13	155

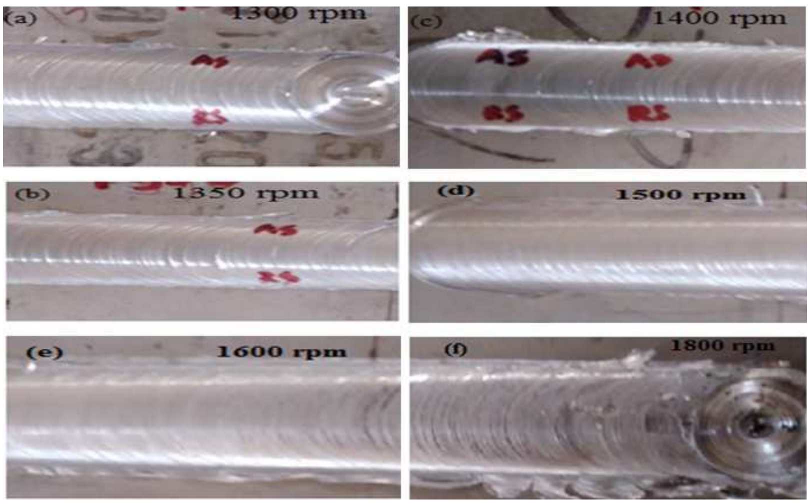

Figure 3: (a-f) Worn Morphologies of Processed Specimens at various Rotational Speeds as Indicated with Pattern of Onion Rings

The metallographies samples were prepared from the fabricated samples in the transverse direction and etched with Keller's reagent (95% H_2O, 2.5% HNO_3, 1.5% HCl, and 1%HF) to understand the particle distribution of boron carbide (B_4C). To know the influence of B_4C particulates on the fabricated composite, hardness was measured using Vicker hardness tester under a load of 100gf, dwell time of 10s at various locations of step size 25µm in the surface composite. The microstructure was observed using a metallurgical microscope.

RESULTS AND DISCUSSIONS

The micrographs of friction stir processed AA2014-T6 with B_4, C particles are shown in Figure 3 (a-f). The micrograph presents a smooth appearance. The selected process parameters are sufficient to produce defect-free regions. The micrographs reveal nugget zone (part of thermomechanically affected zone), thermo mechanically affected zone -(TMAZ) and heat affected zone (HAZ). The process parameters were selected based on trial experiments. Some of the defects encountered in trial experiments such as rough surface are induced by insufficient plastic flow, tool dragging, incomplete bonding, and cracks. It is essential to obtain a smooth crown appearance owing to the fact that each surface irregularity in the crown leads to another kind of internal defects in the surface composite. The tool rotational speed greatly influences the area of the friction stir processed zone, which contains the surface composite. The macrostructure variation in the processed samples of various rotational speeds from 1300 rpm to 1800 rpm is shown in Figure 5. The groove width (0.5mm) and processing speed (20mm/min) was kept constant.

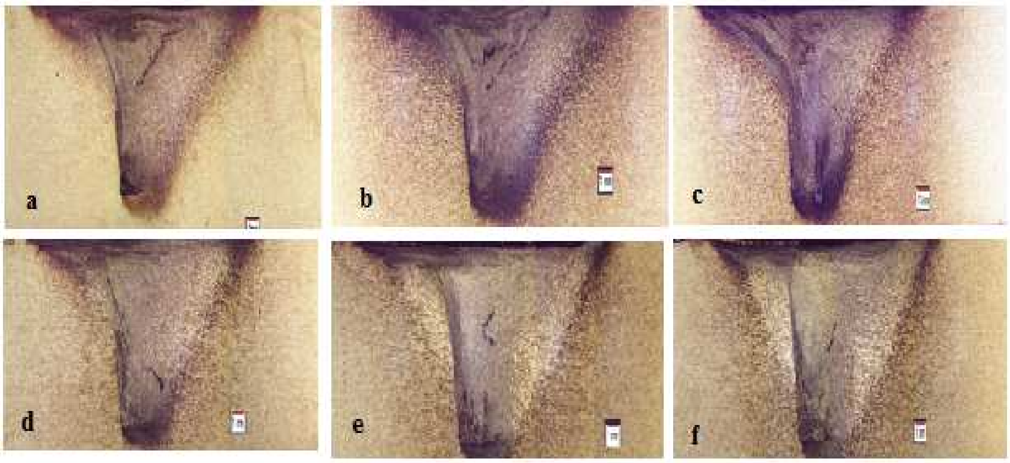

Figure 5: Macrostructure of Friction Stir Zone at Tool Rotational Speed (a) 1300 rpm, (b) 1350 rpm, (c) 1400 rpm, (d) 1500 rpm and (e) 1600 rpm (f) 1800 rpm

As the tool shoulder makes a contact with the base material and traverses, frictional heat is generated. The amount of friction, heat generated is dependent on the tool rotational speed. This frictional heat causes the AA2014-T6 plates to plasticize. The amount of plasticization is dependent on the available frictional heat. Lower the rotational speed, lesser is the plasticization and forms a defective composite and on the contrary, if the rotational speed is higher, high heat input and matrix softening will be more deteriorating the mechanical properties. To overcome this problem an optimum speed that produces considerable heat input and sheer force to make the reinforcement particles easily wrapped by the softened metal and rotated along with the FSP tool resulting in well separation and distribution of particulates in the nugget zone improving the mechanical properties. The microstructure of the base metal AA2014-T6 is shown in Figure 6 and the SEM micrograph of nano B_4C particles is shown in Figure7. Figure 6 The microstructure of the base metal reveals elongated grains. After

friction stir processing the microstructure images clearly reveals the distribution of nano B_4C particles in the AA2014-T6 matrix. The effect of tool rotational speed on the microstructure of the fabricated nano surface composite is shown in Figure 8.

Figure 6: Microstructure of base Metal AA2014-T6

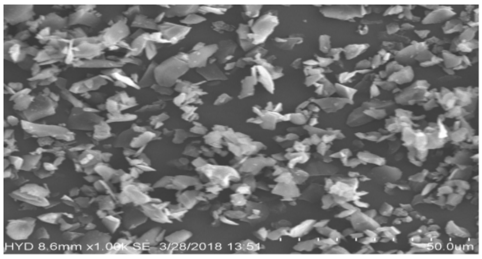

Figure 7: SEM Micrograph of nano B_4C Particles with Elongated Grains

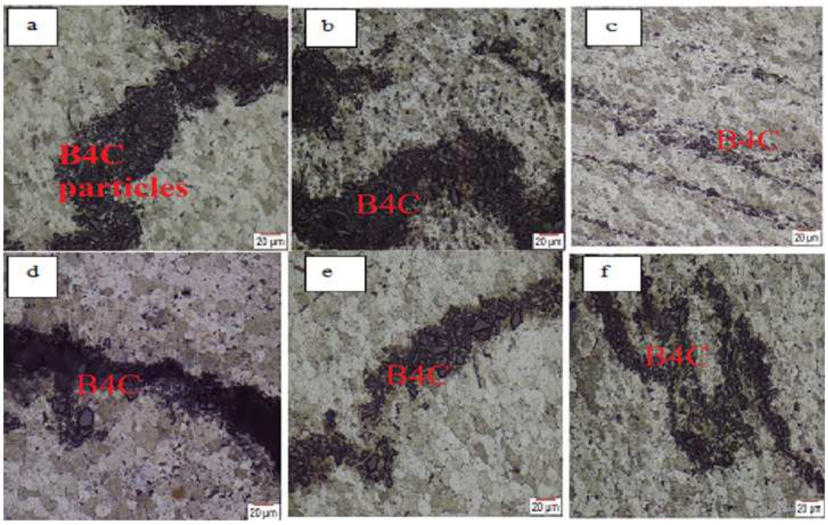

Figure 8: Optical Photomicrograph of AA2014-T6/B_4C Surface Composite at Tool Rotational Speed: (a) 1300 rpm, (b) 1350 rpm, (c) 1400 rpm, (d) 1500 rpm and (e) 1600 rpm, (f) 1800 rpm

The distribution is not uniform at lower speeds, i.e. 1300 rpm, 1350 rpm which is attributed to the agglomeration of B_4C particles at several places as shown in Figure 7 a & b. As the tool rotational speed increased, the agglomeration gradually decreased. The micro image Figure7. d obtained at 1500 rpm shows a fine distribution of B_4C particles as well as grain refinement in the fabricated nano surface composite due to high plastic strain. This high plastic strain and increased stirring action break the agglomerations into the fine dispersion in the AA2014-T6 matrix. Apart from frictional heat generation, tool rotational stirs the plasticized material as well as affected the material flow behavior across the friction stir processed zone. The formation of agglomerations at lower speeds is attributed to insufficient stirring and inadequate material flow from the advancing side to the retreating side. The packed B_4C powder in the groove did not mix with the plasticized AA2014-T6 properly, resulting in the formation of agglomerations. As the tool rotational speed increases, the rate of stirring and the material flow are increased. It is evident from the microimages that the tool rotational speed is an important parameter in the fine distribution of B_4C particles in the matrix enhancing the mechanical properties.

Microhardness survey is conducted to know the effect of tool rotational speed on the microhardness values of the AA2014-T6/B_4C nano surface composite and is as shown in Figure.9. It was found that for increased tool rotational speed,

microhardness decreased. The Avg. Microhardness was found to be 121Hv at 1300rpm and 118Hv at 1800rpm. The maximum microhardness of 188.1Hv was obtained at 1500 rpm as compared to the base metal hardness of 155Hv which is attributed to the fine dispersion of B_4C particles. Fine dispersion of boron carbide particles in the AA2014-T6 Aluminum alloy matrix hinders the free movement of dislocations and enhances the hardness of surface composites, which is validated with an Orwan mechanism [13]. At higher rotational speeds of 1600rpm & 1800 rpm microhardness values were found to be lower when compared at optimum condition of 1500rpm. The presence of agglomerations causes a higher variety of hardness across the surface composite. As tool rotational speed increases, the hardness decreases due to breakup of agglomerations and leading to uniform distribution of B_4C particles.

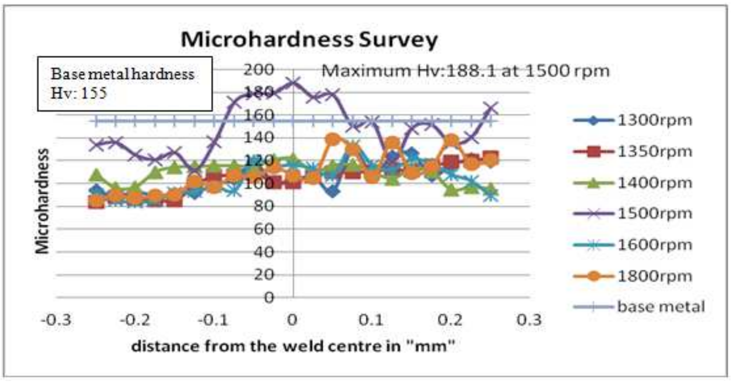

Figure 9: Microhardness Survey of Friction Stir Processed Specimens at Different Tool Rotational Speeds

CONCLUSIONS

AA2014-T6/B_4C nano surface composites were fabricated using FSP and the effect of tool rotational speed on the microstructure and microhardness of the fabricated composite were analyzed and the following conclusions were drawn.

- Defect-free and sound surface composites were fabricated with the selected range of tool rotational speed at the volume percentage of reinforcements and lower processing speed being kept constant (Vol% 2, 20mm/min).
- The distribution of B4C particles in the fabricated nano surface composite was influenced by tool rotational speed. At lower tool rotational speed the particles were agglomerated and not finely distributed, whereas for higher tool rotational speed heat generated is most leading to surface defects. At the optimum speed of 1500rpm fine distribution of B4C particles is seen.
- The matrix grains are refined due to the pinning effect of B4C particles. The microhardness of the nano surface composites was influenced by the selected process range of tool rotational speed. It was found that at an optimum tool rotational speed (1500rpm) the microhardness was higher and beyond this speed, microhardness decreased, which is attributed to the fine uniform distribution of B4C particles. At lower tool rotational speed the distribution of B4C particles was not uniform due to the presence of agglomeration of particles at several places.

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